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NEW WIND POWER STATION

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16. Abstract A wind power plant is described which was used during the fuel shortage that occurred in World War II. Unlike ordinary wind power plants which produced usable power only at wind velocities above 4 or 5 m/s, this power plant was designed to operate over a wide range, charging its battery at low wind speeds, delivering usable power from generator and discharging battery at intermediate speeds, and delivering power and charging its batteries at high wind speeds. The result was exploitation of the wind for a larger number of hours per year and lower costs per kWh of output.

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NEW WIND POWER STATION

E. Rogge and D. Stein

It is well known that wind power plants can normally /358* deliver usable power only at wind velocities above 4 or 5 m/s. Thus the low wind velocities which prevail in the European countries are not fully utilized. This disadvantage results in the generally short utilization time of "wind engines," employed primarily in agriculture. The mechanical/electrical wind power plant for a milling facility described below represents a basically new approach for eliminating the above-mentioned difficulties and permits full utilization of low wind velocities. In addition, the new mode of operation improves the reliability and uniformity of the energy supply and thus increases economy relative to conventonal systems.

Even before World War II, power requirements in the agricultural areas increased so markedly that available energy sources were usually not sufficient to cover needs. This applied particularly to wind-driven mills, for which operation with complex grinding machinery was appreciably impaired not only by the delivery of low and irregular power but particularly by fluctuations in rpm. These problems resulted in conversion to diesel operation or in connection to the rural power grid and thus in the well-known "death of the windmills." It has recently been realized once more that it is desirable to utilize wind power in thinly populated agricultural regions if we wish to save fuel and avoid the establishment of extensive, poorly utilized rural grids. Since economy -- as shown in a number of existent modern wind power plants -- is ensured by proper operation, we can expect that increased recourse will be had to wind power in the coming years,

* Numbers in the margin indicate pagination in the foreign text.

particularly in those areas where connection to the rural grid would be uneconomical.

It would be wrong to think of the return to wind power as a step backward. Modern wind power plants are of course basically different from the old windmills and wind engines, some of which are still in operation. Engineering advances have brought forth new designs. Thus, for example, a new mechanical/electrical wind power plant was put into operation just several months ago near Berlin (Fig. 1); it may prove to be very important for the utilization of wind in agriculture[1]. The system designed and operated by mill owner R. Triller is based on a derrick-type windmill set up at the turn of the century, with sharp-edged blades of diameter 18 m, which could deliver about 3 or 4 kW at /359
a wind velocity of 5 m/s. This corresponds to a power coefficient of c_1 = 0.21 achievable with such blades. In the course of conversion from wind to diesel operation, the mill was equipped with an auxiliary motor in 1913. In 1926 it was completely mechanized by the installation of a diesel engine, which was later converted to producer-gas operation and is presently used for reserve power.

In contrast to many other millers, however, Triller did not abandon wind operation in the conversion to mechanical drive. He set up a small wind turbine for experimental purposes, with four blades and a diameter of 5.8 m, and used this system to produce electrical power. A yearly average of more than 3000 kWh was produced in 1931 through 1941. This delivered energy is quite appreciable if we consider that the system generates about 0.8 kW at a wind velocity of 5 m/s, corresponding to a utilization time of 3750 hours referred to this power level. Thus when the oil

[1] The basic design, mode of operation and economy of mechanical wind power plants (wind engines) and electrical wind power plants to date have been discussed in detail in earlier publications. Cf. D. Stein's articles [1-3].

shortage occurred in 1939/40, Triller resolved to convert his entire system to wind drive again. The compound mechanical/electrical mode of operation discussed below was developed in the process.

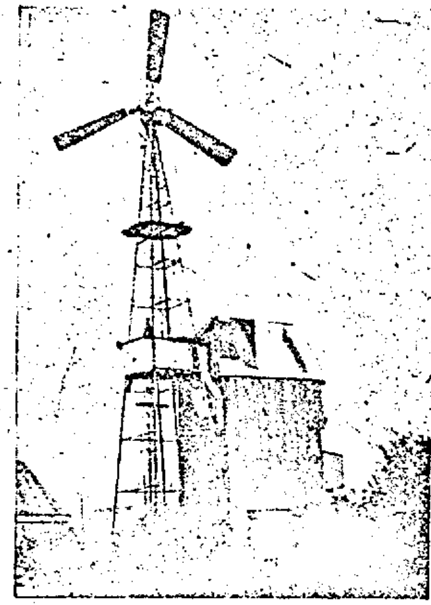

Fig. 1. View of the compound wind power plant.

Design

Mechanical portion: The design of the system can be seen from Fig. 2. Immediately adjacent to the old mill, a 25-m-high iron tower has been set up on which a 3-blade wind rotor with a diameter of 11.20 m has been installed. The wind rotor was designed on the basis of specifications by Bilau and is equipped with rotating trailing edges. Power is transmitted from the rotor via a bevel gear box with a transmission ratio of 1:5, to a perpendicular shaft 14 m long and 50 mm in diameter, over the length of which eight ball bearings are distributed. The vertical shaft drives -- via an additional bevel gear box with a transmission ratio of 1:1 -- the mill transmission, which likewise runs on ball bearings and has a nominal speed of 225 rpm. The machinery listed in Table 1 is then operated from the transmission

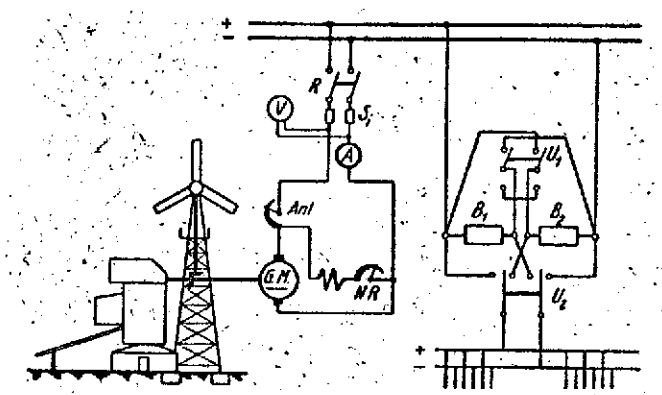

Fig. 2. Schematic of the compound wind power plant.

Key: Anl = starter; U = switch; NR = shunt regulator

TABLE 1. MACHINERY INSTALLED IN THE MILL

System component		Power requirement hp	Power requirement kW
1. Cleaning system Dust cylinder (aspirator), scourer, crusher, "blue meal" cylinder and double elevator		6.0	4.4
2. Grinding system Single roller frame, 300 × 500 mm Double grinding frame, 300 × 500 mm Three elevators Four-part flat sifter	 3.0 4.0 1.6 0.5	9.0	6.6
3. Coarse-grinding system Course-grinding run 1·100 mm diam.		4.0	2.9
		19.0	13.9

The horizontal shaft also extends to the right in the illustration and drives direct-current machinery which is connected to a storage battery. Both the DC unit, which is operated as a generator and as a motor, and the mill transmission can be stopped during operation by means of a friction clutch.

The speed of the rotor is kept at 45 rpm when the halves of the battery are connected in series. The speed ratio is accordingly $u/v = 4.1$ at a wind velocity of 6.5 m/s. The aerodynamically most favorable value (optimum power coefficient c_1) would be reached at $u/v = 5$ for this wind velocity. This would mean, however, that considerably less favorable power coefficients would be assumed at the lower wind strengths which prevail most of the time, and thus overall energy yield would decrease. Thus the blade position was chosen such that $u/v = 5$ is reached at 5.2 m/s.

The electrical portion consists of a low-speed shunt unit (Schwartzkopff design) with a nominal power of 23 kW at 220 V. Speed is reduced to 210 rpm in generator operation by connecting the exciting coils in parallel, corresponding to the nominal battery voltage of 110 V, and to 170 rpm during motor operation -- thereby reducing nominal power to 11 kW. The machine used is considerably overdimensioned; due to the present procurement problems, however, it was not possible to find a low-speed unit of a suitable rating. If redesigned, the dynamo unit would be laid out on the basis of the nominal power of the connected mechanical machinery. A low rpm is necessary to keep frictional losses low, since a second transmission would otherwise have to be installed between the mill transmission and the electrical unit. Moreover, rpm fluctuations in system operation are lower with a lower nominal dynamo rpm.

The battery consists of 54 cells with an output of 360 Ah and can accordingly deliver 30 to 35 kWh of power, depending upon discharge time. Nominal voltage varies between 110 and 150 V, as a function of charge state. A series/parallel system is provided for the battery. The two halves of the battery are connected in series or in parallel by reversing switch U_1 (Fig. 2). The nominal voltage of 55 V in parallel is of course obtained even at a relatively low wind velocity (above about 2.5 m/s). Thus wind strengths of up to 4 or 5 m/s, which otherwise could not be used, can be exploited at high efficiency for charging the battery, independently of compound mechanical/electrical operation.

An ammeter is inserted into the line between the electrical unit and the battery; it can be used to observe the varying current directly. For prolonged lulls in the wind, a 15 kW diesel engine is available for reserve power, the output of which has been reduced to 12 kW, however, by the conversion to producer-gas operation.

Mode of Operation /360

To study the operating behavior of the system, we wish to assume that the power contained by the wind just corresponds, at the instant being considered, to the nominal power of the connected mechanical machines, plus friction losses, and that the main shaft is turning at nominal rpm. In this case, the DC unit will idle along with it. If wind velocity now rises above the earlier value, the excess power at a constant mechanical load will produce an increase in rpm. The voltage of the generator then rises above battery voltage, however, so the motor/generator has an output and will deliver power to the battery (generator operation). The rpm of the system rises only slightly here, since the resistance of the battery decreases with increasing voltage, so that a slight increase in voltage (rpm) is sufficient to take care of the excess power. If wind velocity now drops below nominal value, rpm likewise decreases, and thus so does generator voltage. A reversed current therefore flows from the battery to this unit, which now functions as a motor and takes the missing wind energy from the battery. No regulating equipment is necessary, since an equilibrium is set up for each operating state.

Practical operation proceeds as follows: As soon as the wind has risen to 2 or 3 m/s after a lull, battery charging begins in parallel. The milling machinery is still disconnected here, i.e., only idling losses in the generator must be overcome. The weak wind is therefore well utilized. If wind velocity has increased to 5 m/s, the halves of the battery are connected in series and the mill machinery is cut in. Depending upon the state of battery charge, the entire mill or just a part of it can now be operated at constant rpm, since the deficiency in power is taken from the battery by the machine operating as a motor. If excess power is available, it is pumped into the battery. Thus complete utilization of the wind is ensured up to a preset wind velocity at which the blade regulating system responds. As the wind drops off, the machinery does not immediately need to be shut down -- as explained above. Only when the wind remains relatively weak for a prolonged period must the most favorable combination of mill machinery be selected in each case in order not to completely discharge the battery. In compound mechanical/ /electrical operation, the load placed on the battery is small, however, since it always bears only a portion of nominal power. Thus minimum service life can be assumed to be 10 years.

In contrast to the compound system, operation has hardly been possible with previous mechanical wind power plants (wind engines) at wind speeds below 5 m/s, due to the low and highly fluctuating delivery of power. In ventoèlectric plants, the battery evens these fluctuations out somewhat. Nevertheless, the nominal voltage beyond which charging occurs is not reached below 4 m/s here[2] if partial charging of the battery at low wind speeds is not provided for, as in the case at hand, through a series/parallel circuit system. A basic advantage of such mechanical/electrical coupling is thus that continuous operation is possible in fluctuating winds and that low wind velocities of 2 to 5 m/s, in particular, can therefore be completely exploited.

Operating Speed Behavior

Whereas operating speed follows the fluctuations in wind power in the purely mechanical system with a fixed load and thus cannot, as a rule, be used for driving modern machinery, we can control operating speed as desired in the compound system. We have seen above that operating speed will increase with an increasing supply of power and that the generator will take up the

[2] This value is supposed to have already been reduced to 3 m/s in a modern ventoelectric plant, but only through a considerable outlay in regulating components. It is not yet known, however, with what efficiency the plant operates at these wind velocities.

power which exceeds the mechanical load. Fluctuations in rpm are accordingly a function of the characteristic of the electrical machinery (Fig. 3). In the case of a conventional DC shunt generator, for example, rpm increases by 10% from idle to full load. The rpm fluctuations accompanying maximum wind gusts, from still wind (motor fully loaded) to the limiting wind strength at which the regulating mechanism responds (generator fully loaded), thus amount to ±10%. Sudden wind velocity changes from 0 to 8 m/s rarely occur in cases of medium wind strength; rather, the wind generally fluctuates between 3 and 6 m/s for an average velocity of 4 to 5 m/s. During such changes, the rpm of the compound system fluctuates by ±2 to 3%. In addition, the change in rpm can be affected by suitably designing the electrical machinery, as a function of conditions to be satisfied. A constancy of rpm is thereby achieved which also satisfies the requirements for uniform drive power which are placed on modern mill machinery today.

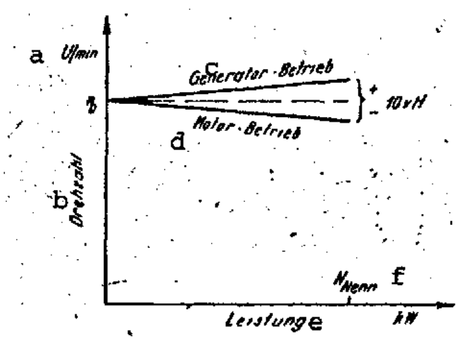

Fig. 3. Characteristics of the electrical machinery for motor and generator operation.

Key: a. rpm; b. Operating speed; c. Generator operation; d. Motor operation; e. Power; f. Nominal power
hV = percent

In addition to the rpm fluctuations discussed above, caused by the gustiness of the wind, however, the nominal rpm of the machinery varies as a function of the battery's state of charge. We know that battery voltage increases with increasing charge. Thus a higher rpm is required to reach the operating point at which the battery begins to take up power. The same phenomenon occurs in the reverse direction as voltage decreases. The limits of rpm fluctuation correspond to the limiting voltages of the battery for charge and discharge. This change in rpm is not disruptive, however, since the operating point continually shifts as a function of charge state. When the battery is charged, frictional losses are merely higher due to the higher nominal rpm.

Regulating Mechanism

The rotating trailing edges developed by Bilau serve as the regulating mechanism. Here, half of the blade can rotate about the longitudinal axis. Operation proceeds in the manner described up to a wind velocity of 8 m/s. Under suitable loads, all winds are completely utilized up to this limit. Beyond it, the rotating trailing edges are actuated and dispose of excess power. In storms, the wind rotor is rotated out of the wind by a mechanical positioning mechanism.

Compound mechanical/electrical operation offers the great advantage that the regulating mechanism normally does not operate at all except above 8 m/s, whereas the regulator used in conventional systems operates at all wind velocities as a function both of the wind available and of load, and thus represents the most sensitive component of the wind power plant. In the compound power plant, this wear is reduced to a minimum. The extremely complex regulator used in many wind power plants is therefore replaced in the case at hand with the simple and very stable rotating trailing edges.

Energy Balance

An energy balance will be compiled to provide an overview of the economy of the compound wind power plant. This is of course a function of local wind conditions. As an example, let us assume a mean year-around wind velocity of v_m = 4 or 5 m/s. Such condi- /361 tions are quite normal and apply to large areas of central and eastern Europe. For instance, recent official measurements indicate mean wind velocity to be 4.2 m/s in Marienwerder (West Prussia) and 5.0 m/s in Königsberg (Prussia). The yearly distribution of wind velocities, i.e. wind frequency, must be established to determine the quantity of energy which can be generated. According to theoretical studies by H. Hullen [4][3], which have been confirmed by measurements, the distribution of wind frequency follows a mathematical law. The corresponding values for the assumed conditions are compiled in Table 2.

TABLE 2. WIND FREQUENCY, POWER AND ENERGY PRODUCTION FOR v_m = 4 AND 5 m/s

Wind speed (m/s)		2,5	2,5 — 3,5	3,5 — 4,5	4,5 — 5,5	5,5 — 6,5	6,5 — 7,5	7,5 — 8,5	8,5 — 10,5
Time per yr. (h)	v_m = 4 m/s	2977	1449	1223	953	698	490	335	386
	v_m = 5 m/s	2200	1230	1139	979	803	634	485	631
Power[1]	kW	—	0,71[2])	1,68[2])	3,40[2])	5,60[3])	7,78[3])	8,27[4])	8,27[4])
Output (in kWh)	v_m = 4 m/s	—	720[4])	1596[4])	3240	3910	3590[4])	2590[4])	3090[4])
	v_m = 5 m/s	—	610[4])	1340[4])	3330	4500	4710[3])	3780[4])	4960[4])

[Note: Commas in numerals are equivalent to decimal points.]

[1] Determined for 3.0-4.0 m/s in each case. Mechanical and electrical losses are not included here, since they have not yet been precisely measured. These losses are opposed by the gain in power -- likewise not included -- which is obtained through the increase in wind speed at a height of 25 m relative to the values taken close to the ground, on which these figures are based. This increase in power, which also has yet to be determined, at least compensates for the mechanical and electrical losses.

[2] $c_1 = 0.42$

[3] $c_1 = 0.35$

[4] $c_1 = 0.25$

[4] $\eta_{blade} = 0.70$.

The output of the wind power plant described is shown in Fig. 4 as a function of wind velocity for setting up the energy balance. The solid curve represents actual power and the dashed curve represents theoretical power for a constant c_1. For the real power curve, an optimum power coefficient of $c_1 = 0.42$ is

[3] See also [5].

assumed from 3 to 6 m/s, whereas we have set c_1 = 0.32 and 0.25 for the higher wind velocities, since it is known that efficient utilization of wind energy deteriorates with decreasing speed ratio u/v. The present case is based on a nominal power of 6.6 kW, which is reached at 6.5 m/s, since the grinding machines which represent the basic load are all being operated at this level. We can derive the follow operating states from the power stage shown in Fig. 4:

1. charging operation (a)
2. compound operation: compound discharging operation (b); compound charging operation (c)

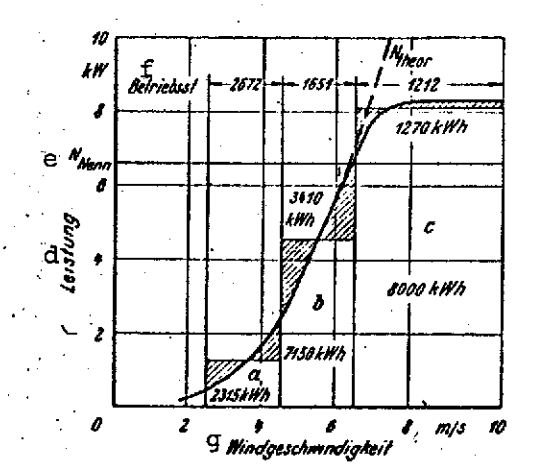

Fig. 4. Energy balance for v_m = 4 m/s. The kWh data plotted in the graph represent averaged quantities of work delivered by the wind rotor or by or to the battery for the basic nominal power of 6.6 kW.

Key: a. Charging operation; b. Compound discharging operation; c. Compound charging operation; d. Power; e. Nominal power; f. Operating stage; g. Wind velocity

Charging operation normally covers wind velocities from 2.5 to 4.5 m/s, in which case both halves of the battery are being charged. Operating speed is reduced by the correspondingly lower voltage. Frictional and electrical losses are thereby kept to a minimum. Moreover, an optimum power coefficient is obtained, so that gentle winds can be exploited as well as possible. Completely automatic operation is possible here if a relay ensures that the battery will be cut out when the charged state is reached. Winds of 2.5 to 4.5 m/s, which blow 2672 hours and 2369 hours out of the year, respectively, can thus be fully utilized. Since the quantity of energy generated goes through the battery in any case, however, electrical efficiency can be assumed to be 0.70.

Compound discharging operation can start, for a nominal load, at a mean wind velocity above 4.5 m/s. The portion lying under the power curve is delivered directly by the wind rotor in the form of mechanical energy, while the deficiency above the curve is taken from the battery by the electrical unit, operating as a motor. The ratio of electrical to mechanical energy fluctuates every minute, corresponding to the power content of the wind. According to Table 2, such compound mechanical/electrical operation can be performed 1651 hours and 1782 hours per year. Since the mill machinery requires a certain amount of maintenance, however, completely automatic operation is not possible if personnel are not available at night. Thus a utilization factor must also be applied.

If mean wind velocity increases beyond 6.5 m/s, the excess energy is pumped into the battery. We then have compound charging operation. Such a mode of operation is theoretically possible for 1212 hours and 1750 hours per year. It is necessary to likewise include a utilization factor here for the same reason as for discharging operation.

The boundaries between the different operating states in the compound wind power plant are of course not fixed. The data presented are associated with average wind velocities, with no consideration given to gusts. Moreover, battery charging is of course possible at night, up to the limiting wind velocities, if compound operation is not utilized. Conversely, the excess energy associated with high wind velocities can be taken up by cutting in additional mechanical equipment, say the cleaning or coarse-grinding machines in the case at hand. Nominal power is likewise established arbitrarily, depending upon what machines represent the basic load. The compound wind power plant thus provides the possibility of adapting at any time to actual wind conditions and to the battery's particular state of charge and thus of obtaining maximum energy from the wind.

Conditions in the compound wind power plant will now be studied quantitatively on the basis of the above qualitative considerations. If it is assumed that operation is uninterrupted and if battery efficiency is taken into consideration, then, as Table 2 indicates, 18,735 kWh energy can be generated at $v_m =$ $= 4$ m/s and 23,240 kWh at 5 m/s. Battery efficiency is taken into consideration for only about 30% of the energy produced at the wind strengths associated with compound charging operation here, since it can be assumed that the remaining quantity of work is converted directly into mechanical energy. In general, however, we cannot expect complete utilization of the available wind energy; rather, it is necessary to accept interruptions in operation, particularly during the night. A utilization factor of $\varepsilon = 75\%$ is therefore assumed for the energy production on which /362 the following economy calculations are based, as generally achieved in practical operation with the system described. For a purely mechanical wind power plant, this value would drop to 60%, since the battery, which acts as a buffer, is then absent, and brief gusts and lulls cannot be taken care of. The outputs which are possible with the compound system and the wind engine are shown in the energy balance (Table 3). It has been assumed here that the wind engine can only operate continuously above 5.5 m/s. This assumption is generally applicable except for wind-operated drainage and irrigating systems. For operations in which the assumed level of utilization cannot be achieved, a correspondingly smaller ε should be substituted in the following for calculating kWh costs.

TABLE 3. ENERGY BALANCE FOR COMPOUND WIND POWER PLANT AND WIND ENGINE FOR v_m = 4 AND 5 m/s (ε = 0.75 and 0.60)

Yrly. av. wind speed ....m/s	Compound system 4	Compound system 5	Wind engine 4	Wind engine 5
Output (in kWh)				
2,6 – 4,6 m/s	2 315	1 960	—	—
4.6 – 6,6 m/s	5 370	5 880	2 340	2 600
6,5 – 10,6 m/s	6 940	10 100	5 870	8 500
Total output kWh	14 625	17 930	8 210	11 000

If battery efficiency and the utilization factor are taken into consideration, the energy balance indicates an output of 14,625 kWh and 17,930 kWh for the compound system as opposed to 8,210 and 11,000 kWh for the wind engine. In the first case this means 78% greater output and 61% in the second case. We thus see that the compound system provides a basic improvement in wind power utilization, particularly in areas with poor wind conditions. It must also be taken into consideration, however, that the compound system is suitable for driving ordinary operating machinery, whereas the wind engine has so far been usable only for very gross operation or "staple" work. In terms of its usability, the compound system is therefore similar to a wind power station in which the entire mechanical energy developed is first converted into electrical energy which is then in turn employed to drive motors and for lighting and heating purposes. The wind power station operates at a lower efficiency, however, due to conversion losses and because it cannot exploit gentle winds. The compound system thus entails basic advantages for agricultural goods and rural commercial facilities in which a force load plus a small lighting load primarily occur, and is particularly suitable for relieving diesel and producer-gas engines in remote areas. It seems quite possible, moreover, to operate the system with three-phase electrical power and to use the public power grid for equalization, in place of the battery. The preliminary theoretical work required to solve this problem is being carried out at present. The economy aspects of such a mode of operation with regard to payment for delivery and procurement are also being studied in detail, since such a compound operation could make things considerably easier for the public utilities in agricultural areas.

Economy

Actual costs for the mechanical/electrical wind power plant described cannot be used as the basis for economy calculations, since used components have largely been employed for assembling it. List prices have therefore been given in the compilation. In detail, the costs (in reichsmarks) are associated with the following system components:

1.	Tower, 25 m high, including foundation and vertical shaft	3100.00
2.	Wind rotor with bevel gear box	3500.00
3.	Generator (SSW), 6 kW, 110 V, 240 rpm, including starter and shunt regulator	3000.00
4.	Storage battery (Afa), 54 cells, Type KL8	3000.00
5.	Switching system, lines	200.00
6.	Assembly	750.00
	Total	13,850.00

For determining yearly costs, a service life of 10 years is assumed for the battery, 20 years for the mechanical components and the tower, and 25 years for the generator. The average depreciation rate is thus 4.02%. Interest is assumed to be 4%. Service required for the compound system is low and is limited primarily to adapting the operating state to prevailing wind conditions. We thus find yearly outlay to be as follows:

1.	Depreciation, 4.02% of 13,850 RM		556.00 RM
2.	Interest, 4% of 13,850 RM		554.00 RM
3.	Maintenance		270.00 RM
4.	Service		120.00 RM
		Total	1500.00 RM

This amounts to 10.4% of the invested capital and is on the order of magnitude of yearly costs for water-driven power systems. For a complete calculation of economy, it would also be necessary to include reserves for covering prolonged lulls in the wind. This will not be done here, since at least the same type of reserve must also be provided for the wind engine and wind power station, while this study is merely meant to show the difference between the compound wind power plant and these other systems

If we make the same kind of economy calculations for a wind engine of the same dimensions as we have done for the compound system, we obtain fixed costs (tower, wind engine and assembly) of 7350 RM. Attendance plays a considerable part in yearly outlay, however, since the wind engine requires continuous supervision in the operation of machinery. In contrast to the compound system, operating personnel are thus required here to primarily look after the wind engine. Yearly expenses are then found to be the following:

1.	Depreciation, 3.36% of 7350 RM		247.00 RM
2.	Interest, 4% of 7350 RM		294.00 RM
3.	Maintenance		129.00 RM
4.	Service		480.00 RM
		Total	1150.00 RM

Table 4 shows energy costs based on these yearly expenses. As can be seen, the operating cost is considerably lower for the compound system than for the wind engine, in spite of the considerably higher fixed costs. It should also be noted here that it is precisely under relatively poor wind conditions that the compound system comes out better than the wind engine. For calculating actual energy prices, it is also necessary to add expenditures for the reserve system to the costs listed in Table 4. Operating costs are normally thereby increased by about one-third; here, too, lower costs will occur for the compound system than for the wind engine, for the reasons discussed. If we now compare the energy costs so determined for the mechanical/electrical wind power plant with those for a purely electrical wind power station for which we can use a kWh price of 0.20 RM [6] for modern designs, we again find the compound system to be superior. The reasons for the economic inferiority of the wind power station for the purpose described lie in the considerably more complex mechanical /363 design, particularly the regulating provisions, and in the appreciable disadvantages already stressed relative to the compound wind power plant.

TABLE 4. ENERGY COSTS FOR THE COMPOUND SYSTEM AND THE WIND ENGINE WITH COMPLETE AND PARTIAL UTILIZATION FOR v_m = 4 AND 5 m/s

Yearly average wind speed m/s	Compound system		Wind engine	
	4	5	4	5
Energy costs (in reichspfennigs/kWh)				
for complete utilization, $\varepsilon = 1.00$	8.0	6.5	9.3[1]	7.0[1]
for partial utilization, $\varepsilon = 0.75$	10.3	8.4	14.0[2]	10.4[2]

[1] It is necessary to use $\varepsilon = 0.9$ for the wind engine, even during full utilization, since the use of energy cannot be completely matched to delivered power, even under careful and continuous supervision.

[2] $\varepsilon = 0.60$

Measurements

In order to illustrate the compound operation described, the flow of power between the battery and the electrical unit has been plotted for compound discharging operation. For this purpose, the ammeter located in the line was read every 30 sec; the current curve obtained is shown in Fig. 5. During this period, voltage fluctuations ranged between 95 and 103 V. The current curve thus provides a measure of the power taken from the battery. During this series of measurements, the mill was being operated with a power of 5.5 kW. Wind velocity was determined with a Deuta-Morell cup anemometer; the average is 5.5 m/s, which corresponds, according to the power curve in Fig. 3, to a power of 4.5 kW. The average deficiency of 1 kW was filled by the battery, which delivered a mean current of 10.2 A during the series of measurements. The fluctuations in current (power) provide a good picture of the actual conditions in the varying current. It should merely be noted that the measured current data likewise represent averages only. In actuality, the wind and thus the power taken from the battery also fluctuate considerably during the reading period of 30 sec. Measurements are to be made with recording instruments in the near future to determine these conditions precisely; the results will be reported.

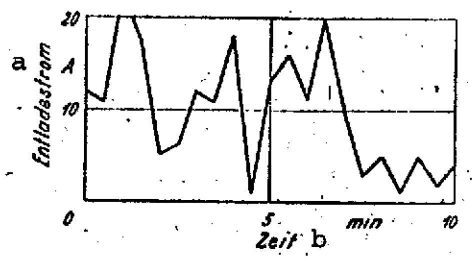

Fig. 5. Discharge current during compound operation. Recorded from 6:39 PM to 6:49 PM on August 27, 1943. Mechanical load 5.5 kW, mean wind velocity 5.5 m/s.

Key: a. Discharge current; b. Time

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